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Will the Nordic Power Market Remain competitive?

Jan V. Hansen, Jens Hauch and
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Abstract:

There is world-wide a clear trend towards the deregulation of power markets. The question is: will the markets stay competitive in the longer run or develop into situations of damaging market concentration?

Studies based on analyses of historical data have not found any indication of abuse of market power in the Nordic power market, Nord Pool. We argue that historical data could be a misleading benchmark for evaluating Nord Pool because of temporary disequilibrium phenomena. The present situation is characterized by excess generating capacity, a heritage from the publicly regulated system. This is one of the major differences between the Nordic electricity market and the liberalized power markets in the UK and California, which are characterized by scarce capacity. Furthermore, the concentration of power companies is rather low in the Nordic area compared to other power markets, but there is a current trend towards higher concentration due to mergers and reciprocal acquisition of shares.

We adopt a scenario approach and simulate likely market structures for 2005, when capacity is expected to be normal. Simulations are based on a numerical model that provides estimates for prices in the Nordic power market under assumption of Cournot competition with an exogenously specified number of identical competitors and a fringe of small price-taking competitors. A novelty compared to other studies of this subject is the inclusion of district heating produced jointly with electricity. We find that the future potential for excess profits is surprisingly large when compared to a traditional measure of market concentration, the Hirschman-Herfindahl Index.

Keywords: Oligopoly, Cournot competition, power markets, district heating.

JEL: D4, L9, Q4.

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1 Introduction

The process of deregulation of the electricity markets in the Nordic countries has been going on now for more than a decade. Starting in 1991, the strictly regulated electricity market in Norway was opened up for competition in power generation and supply, while transmission and distribution continued to be regulated monopolies. Since 1995 all end-users have been free to choose suppliers of electricity. The Swedish and Finnish markets were reorganised in 1996, largely inspired by the Norwegian model. At the same time a common Norwegian-Swedish spot market, Nord Pool, was opened. In 1998 Finland joined Nord Pool, and a common Finnish-Norwegian-Swedish electricity market emerged.

Denmark has been lagging behind the other Nordic countries with respect to deregulation of the electricity market. The deregulation process first started in 1999, when competition in power generation and supply was introduced, but small consumers will not be free to choose their suppliers until 2003. However, Danish transmission companies have been active on Nord Pool since 1996.

The main purpose of this paper is to quantitatively evaluate the consequences of Nordic power producers setting prices and quantities to maximize profits. We present a numerical model that provides estimates for prices in the Nordic power market under assumption of Cournot competition with an exogenously specified number of identical competitors. As the assumption of identicalness is strong, the model also provides an opportunity for sensitivity analysis with a fringe of small price-taking competitors that are too small to have an influence on the market price on their own. We do not model any tacit collusion, and assume that imperfect competition stems from barriers to entry. A novelty compared to other studies of this subject is the inclusion of district heating produced jointly with electricity.

Studies based on analyses of historical data have not found any indication of abuse of market power in Nord Pool. We argue that historical data could be a misleading benchmark for evaluating the Nordic power market because of temporary disequilibrium phenomena. The present situation is characterized

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1) This article is partly based on Kromann (2001). We are grateful to the Danish Strategic Environmental Research Programme for financial support. The views expressed are ours alone.

by excess generating capacity, a heritage from the publicly regulated system. This is one of the major differences between the Nordic electricity market and the liberalized power markets in the UK and California, which are characterized by scarce capacity. Furthermore, the concentration of power companies is rather low in the Nordic area compared to other power markets, but there is an ongoing tendency towards higher concentration due to mergers and reciprocal acquisition of shares. We adopt a scenario approach and simulate likely market structures for 2005 in which capacity is assumed to be normal and where the new competition regime is well established. We find that the future potential for excess profits is surprisingly large when compared to a traditional measure of market concentration, namely the Hirschman-Herfindahl Index (HHI).

Section 2 gives an overview of previous analyses of imperfect competition in power markets in the UK, California and the Nordic countries. In section 3 we present a theoretical framework for a perfect competition model of the Nordic energy markets serving as benchmark for the scenarios with imperfect competition outlined in section 4. The simulation results can be found in section 5, followed by conclusions in section 6.

2 Previous Analyses of Market Power in Power Markets

In implementing the oligopoly equilibrium approach there are basically two alternative behavioural assumptions which crucially affect conclusions: Cournot and Bertrand behaviour. Cournot behaviour assumes that strategic firms employ quantity strategies, i.e. such a firm chooses the quantity it will produce taking as given the output being produced by all other strategic firms.

Because of Kreps and Scheinkman (1983), Cournot competition is often thought of as an investment game in which none of the producers have any initial capacity and where they all simultaneously decide on some investment on the basis of the known demand and the number of other players in the game. The investment is a credible quantity commitment (it might take some time to get the investment ready for production) and the players can thereafter go into price competition. Due to, for instance, barriers to entry, only an exogenously determined number of firms are allowed to participate in the investment game.

The other basic non-cooperative equilibrium concept, the Bertrand equilibrium, in which firms compete in prices, is supported by the assumption that any firm can capture the whole market by lowering prices below others and can expand output to meet such demand. This assumption is in conflict with the generation capacities constraint in electricity markets, which exists because it takes time to build up new capacity and because production plants have to be idle for maintenance from time to time. Electricity markets are more like the Bertrand equilibrium with capacity constraints, where prices will not typically be equal to marginal costs.

The Supply Function Equilibrium (SFE), which describes oligopoly price and quantity choice under uncertainty, encompasses Cournot and Bertrand behaviour as extreme outcomes. The SFE concept, introduced by Klemperer and Meyer (1989), applies well to the electricity hour-by-hour auctions used in many liberalized electricity markets.[2] This approach is based on smooth, twice-differentiable cost curves. Electricity producers submit bid schedules to supply a market under uncertainty, and the bids submitted can be used as credible quantity commitments. Normally this approach does not guarantee a unique solution.This opens up the possibility of Cournot competition as the worst case outcome of the auctions when uncertainty is very low. At higher uncertainty the prices converge towards the Bertrand equilibrium price.

Green and Newbery's (1992) major analytical insight is to have observed that demand uncertainty, as represented in Klemperer and Meyer (1989), is formally identical to demand variation over time. Their results show that there is a great potential for market power in the British market, especially regionally, due to transmission capacity constraints. Green and Newbery conclude that if the British power industry had been divided into five equal sized companies, instead of two, the potential for market power would have been much reduced.

A number of criticisms of Green and Newbery (1992) have been made. If the range of variation in demand is finite then the solution to the model is undefined, since almost anything between the Cournot and Bertrand solutions can be an equilibrium; see Bolle (1992) and Wolak and Patrick (1997). Another troubling assumption is that generators submit continuously differen-

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2) Borenstein et al. (1999) criticize the SFE model because it has difficulties with including a competitive fringe, bilateral contracts, starting costs, plants running idle for standby dispatchment and other short term phenomena.

tiable supply functions. von der Fehr and Harbord (1993) analysed bidding strategies in the electricity pool for discrete generating units. This gives a step-like supply function rather than a continuous schedule. They showed that for some patterns of demand and allocations of capacity there was no equilibrium in pure strategies.[3] For a discussion of pros and cons of the SFE and bidding strategies see Newbery (1997).

The first study attempting to measure actual, instead of potential, market power in the British power industry was Wolak and Patrick (1997).[4] They found that the combinations of market structure and market rules provide the generators with an incentive to withhold capacity in certain half-hour periods in order to drive up the pool price.

Wolfram (1999) also examined the British markets. She attempted to measure actual market power in the British market based on unique plant specific data over a broad period (observations on the equilibrium pool prices and quantities from nearly every half-hour period during 18 months in the period 1992-94). She found that the actual market price mark-up above marginal cost was much smaller than that predicted as the highest possible price in the SFE approach by the model of Green and Newbery (1992). Wolfram offers two complementary motives for the behaviour of generators: to deter new entrants and to prevent substantial regulatory action.

Borenstein and Bushnell (1999) simulated the potential for market power on the fully deregulated Californian market in an *ex ante* analysis assuming Cournot behaviour. They found evidence for significant market power in hours with high demand, especially in periods when hydro power output is low due to seasonal variation. Borenstein et al. (1999) studied the interaction between market power and transmission capacity constraints. They found that at least one firm could have an incentive to strategically induce transmission congestion, in order to exercise market power in local markets.

Joskow and Kahn (2001) present an *ex post* analysis of pricing behaviour in California's electricity market during summer 2000. They simulate competitive wholesale prices for electricity, taking into account changes in natural

[3] See Marín and García-Díaz (2000) for a generalization of von der Fehr and Harbord's approach in the case of deterministic demand.

[4] Both Green (1994) and von der Fehr and Harbord (1993) compare the generator's bid prices to their estimated costs on several representative days.

gas prices, electricity demand, supply of electricity from other states, and the prices of NOx emissions permits during this time period. They conclude that a significant fraction of the increase in wholesale electricity prices can be explained by these factors. However, there is a non-trivial gap between the competitive benchmark prices that they estimate and actual prices. Joskow and Kahn attribute this difference to suppliers exercising market power; this is confirmed by a capacity withholding analysis indicating a substantial imbalance between maximum levels of generation and observed levels.

Amundsen et al. (1998) examined the Nordic market. Simulating both Cournot and perfect competition equilibria, they found that with free trade in the Nordic area Cournot equilibrium price is close to the perfect competition price. In the case of no inter-country trade the differences between the two regimes were much greater. The study also confirms that the physical flows of electricity between the countries in the trading regime are within existing transmission limits.

von der Fehr et al. (1998) and Amundsen and Bergman (2000) described and analyzed the impact of higher concentration in the Nordic market due to mergers and cross-ownership. On the basis of a numerical model, and assuming Cournot quantity setting behavior, Amundsen and Bergman showed that partial ownership relations between major players on the Norwegian-Swedish power market tend to increase horizontal market power and hereby the price of electricity.

Hjalmarsson (1999) is the first econometric study of market power in the whole Nordic spot market, and is based on data for the period 1996 to April 1999.[5] Using a dynamic augmentation of the Bresnahan-Lau model, Hjalmarsson clearly rejects the hypothesis of market power, both in the short and long run. He concludes that the low market concentration in the Nordic market compared to the British and Californian electricity markets is the most likely explanation of competitive behaviour.

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5) Johnsen et al. (1999) focuses on five Norwegian bidding areas. They find some evidence of market power in two of the local markets due to transmission constraints.

3 A Perfect Competition Framework

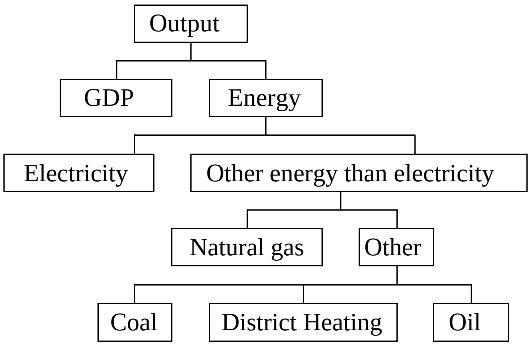
The framework presented is based on a partial equilibrium model by Hauch (2000) describing supply and demand for energy and other goods and services in Denmark, Finland, Norway and Sweden. The model is calibrated on data for 1995 and is an annual model. Thus, it does not account for seasonal or daily variation in demand and supply.

Electricity is traded, and households optimize their utility and producers their profit. The model is a hybrid model: a "bottom-up" system describes production of electricity and district heating, while a "top-down" system of production and utility functions describes supply of other goods and demand. The bottom-up modelling allows a detailed description of energy production, which is our main point of interest, while the top-down system is a widely used method for modelling economic aggregates.

3.1 Top-down Modelling of Non-energy Supply and Demand

Five sectors (the heavy, light, chemical and food/wood industries and the service sector) produce goods for consumption using electricity and district heating. Fuel inputs are supplied by the world market at exogenous prices. An aggregate of "other inputs than energy" represents the value added from other commodities. This aggregate covers 97 percent of the inputs used, and this is why the model claims only to be a partial equilibrium model. The industrial input nest structure is shown in figure 1.

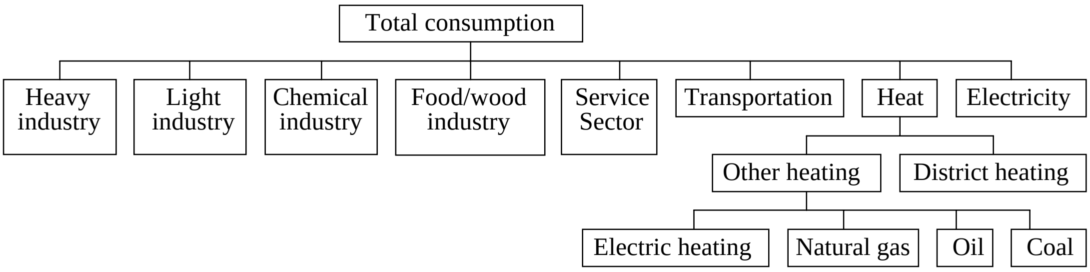
Figure 1 Industrial input nest structure



The outputs of the five sectors are used for household consumption, which also includes transportation, electricity and heating. The price of transportation is proportional to the oil price, so transportation can also be said to be supplied inelastically by the rest of the world. Heating is a nested utility function including electric and district heating, oil, gas and coal. All commodities are priced separately for all four countries in order to allow, for example, different levels of taxation. The nesting of the household utility function is shown in figure 2.

As all utility and production functions are well-behaved (the functions used are Stone-Geary, CES and Leontieff), the aggregate utility function is also well-behaved. Then the aggregate demand function for electricity is also continuous, twice differentiable and decreasing with electricity price.

Figure 2 Household demand nest structure



3.2 Bottom-up Modelling of Supply of Electricity and District Heating

The stepwise marginal cost structure which is most suitable for this form of production is modelled with a bottom-up system. The production of electricity and district heating can be divided into four broad technology types:

- **Condensing** technologies produce $\eta < 1$ energy units of electricity for each energy unit of fuel input. η is the energy coefficient. The energy loss (due to excess heat) cannot be utilized for district heating purposes. Condensing technologies use oil, coal and gas as fuel inputs. It is convenient also to model nuclear, hydro and wind power as condensing technologies, as the equations describing these technologies are identical to those of genuine condensing technologies.

- **Backpressure** technologies can utilize the excess heat from electricity production to produce district heating. The η's associated with backpressure technologies account for the sum of electric and district heating energy produced from one energy unit of fuel input. Cm is used to designate the electricity-heat ratio. Backpressure technologies are found in both small and large scale and use oil, coal, gas and bio fuels.
- **Extraction-condensing** technologies run in either condensing or backpressure mode. Extraction-condensing technologies are only used on the large scale and use oil, coal and gas as fuel inputs.
- **Pure district heating** technologies do not produce electricity. It is assumed that only bio fuels are used for this technology. The η-values associated with district heating are interpreted as total energy output for each energy unit of fuel input.

District heating must be powered by small scale technologies when the areas supplied are too sparsely populated to support large scale plants. Strictly speaking there are two separate markets for district heating, but it is more convenient to make the model sensitive to scale and geography by forcing some minimum share $0 \leq \theta \leq 1$ of district heating to be powered by small scale technologies.[6] θ corresponds to the observed ratio between large and small scale district heating.

Whereas district heating must be delivered locally, electricity can be traded internationally. Hauch (2000) models an international transmission system with capacity limits and transportation costs. Assuming that the transmission system is operated under perfect competition (equivalent to perfect regulation), electricity is transmitted between countries if the difference between prices is greater than the transmission cost. This causes the national demand curves for electricity (exports included) to become kinked.

For this reason we here assume no transportation costs and capacity limits for international transmission, as the model will otherwise become too compli-

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6) Small scale technologies can also supply densely populated areas.

cated.[7] Transmission systems can also be used strategically by congesting a transmission line. The underlying data of our model is too sparse to describe strategic interaction through transmission. Furthermore, as the scope is a rough estimate of potential market power, the inclusion of costly and limited transmission without strategic interaction cannot justify the extra complication which this would cause. For further evaluation of the Nordic market for electricity, this is an obvious topic to investigate.

We have four countries and we assume that all producers have an equal share of the capacities for all technologies.[8] For each technology k and country i, let $H^{b}_{k,i}$ and $H^{p}_{k,i}$ denote the heat output from backpressure and pure district heating production respectively. Also, let $E^{b}_{k,i}$ and $E^{c}_{k,i}$ denote the electricity output from backpressure and condensing production. Let $F^{b}_{k,i}$, $F^{c}_{k,i}$ and $F^{p}_{k,i}$ denote the fuel use, and $K^{inv}_{k,i}$ denote any added capacity, while $K^{ini}_{k,i}$ is the existing capacity. For some technologies an upper capacity limit, $K^{max}_{k,i}$, exists.[9] P^{H}_{i} and P^{E} denote the prices of produced heat and electricity, and $P^{F}_{k,i}$ is the price of technology-specific fuel. The price of capacity is $P^{K}_{k,i}$, which is exogenously set to the capital cost of one fuel unit input at the given interest rate. E, H^{l}_{i} and H^{s}_{i} are the total amounts of electricity produced, and large- and small-scale district heating supplied in equilibrium respectively. Finally, let d_k be a binary parameter assigned the value 0 or 1 for large- or small-scale district heating technologies.

For convenience, these calculations assume that each technology can produce in condensing, backpressure and pure district heating modes. No technology can in fact do so, but when the appropriate η's are set to zero, cost minimization will rule out the impossible production modes. The producers' profit maximization problem is:

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[7] Because of the stepwise cost structure, the demand curve gets kinked as a result of the introduction of fringe supply; this will be discussed later. In section 4.2 we show that it is necessary to check each kink separately, as they may represent opportunities for extra profit.

[8] Note that though the capacities are also separated by countries, there is no national distinction in ownership: the producers own an international portfolio of production capacity.

[9] This applies for example to some unused Norwegian hydropower potential.

$$\max \Pi \left(F_{k,i}^{b}, F_{k,i}^{c}, F_{k,i}^{p}, K_{k,i}^{inv}\right) = \sum_{k,i} P_{i}^{H}\left(H_{k,i}^{b} + H_{k,i}^{p}\right)$$
$$+\sum_{k,i} P_{E}\left(E_{k,i}^{b} + E_{k,i}^{c}\right) - \sum_{k,i} P_{k,i}^{F}\left(F_{k,i}^{b} + F_{k,i}^{c} + F_{k,i}^{p}\right) - \sum_{k,i} P_{k,i}^{K} K_{k,i}^{inv} \tag{1}$$

subject to the conditions for all technologies and countries, k and i, that

$$E_{k,i}^{b} = \frac{Cm_{k,i}}{1 + Cm_{k,i}} \eta_{k,i}^{b} F_{k,i}^{b} \tag{2}$$
$$E_{k,i}^{c} = \eta_{k,i}^{c} F_{k,i}^{c} \tag{3}$$
$$H_{k,i}^{p} = \eta_{k,i}^{p} F_{k,i}^{p} \tag{4}$$
$$Cm_{k,i} = \frac{E_{k,i}^{b}}{H_{k,i}^{b}} \tag{5}$$

$$F_{k,i}^{b} + F_{k,i}^{c} + F_{k,i}^{p} - K_{k,i}^{ini} - K_{k,i}^{inv} \leq 0 \tag{6}$$
$$\theta H_{i} \leq H_{i}^{s} \Leftrightarrow \sum_{k} (\theta_{i} - d_{k}) \left(\frac{1}{1 + Cm_{k,i}} \eta_{k,i}^{b} F_{k,i}^{b} + \eta_{k,i}^{p} F_{k,i}^{p} \right) \leq 0 \tag{7}$$
$$K_{k,i}^{ini} + K_{k,i}^{inv} - K_{k,i}^{max} \leq 0 \tag{8}$$

The problem is constrained by the energy efficiency in the three technology types (equations 2, 3, 4), the electricity-heat ratio (equation 5) and the capacity limits (equation 6). Equation 7 is the decentralized district heating condition, and equation 8 represents potential limits imposed on total capacity. Substituting equations 2 to 5 into equation 1, the problem can be solved with respect to fuel and capital inputs (henceforth we refer to the three types of fuel input and added capacity for all technologies and countries as the input vector) as a Kuhn-Tucker problem, because the derivatives of the profit function and the constraints with respect to the input vector are continuous. This yields the following (for all k technologies and i countries) four first-order conditions and (not shown) seven complementary slackness conditions:

$$\frac{\eta^b_{k,i}}{1+Cm_{k,i}}\left(P^H_i + Cm_{k,i}P_E - (\theta_i - d_k)\,\lambda^{dec}_i\right) - P^F_{k,i} - \lambda^{cap}_{k,i} \leq 0 \qquad (9)$$

$$\eta^c_{k,i}P_E - P^F_{k,i} - \lambda^{cap}_{k,i} \leq 0 \qquad (10)$$

$$\eta^p_{k,i}P^H_i - P^F_{k,i} - \lambda^{cap}_{k,i} - \eta^p_{k,i}\,(\theta_i - d_k)\,\lambda^{dec}_i \leq 0 \qquad (11)$$

$$\lambda^{cap}_{k,i} - \lambda^{max}_{k,i} - P^K_{k,i} \leq 0 \qquad (12)$$

There are three slack variables. $\lambda^{cap}_{k,i}$ is the shadow value of any added capacity. If this value is equal to the capacity cost, investment is made. Thus the shadow value for new capacity in some technologies can only be larger in the case that the technology has a capacity limit. Here, $\lambda^{max}_{k,i}$ is the shadow value of expanding this capacity limit. In this sense $\lambda^{cap}_{k,i}$ is a gross shadow value with respect to investment cost, whereas $\lambda^{max}_{k,i}$ is a net shadow value which is always zero when there are no capacity limits. Finally, $\lambda^{dec}_{k,i}$ is the shadow value of the decentralized district heating production constraint.[10]

4 Imperfect Competition

In this study we assume the oligopoly equilibrium approach, in line with the studies of Amundsen et al. (1998) and Borenstein et al. (1999), by analysing a variant of the Cournot-Nash concept of firm strategies and beliefs. Our strategically acting oligopolists can take capacity out of production or omit to make investments. Small firms with limited production capacities, referred to below as the competitive fringe, are modelled as price-takers, both in their own behaviour and in how they are viewed by strategic players in the market.

The market for district heating is a natural monopoly because of the large costs and capital intensity in the distribution, and it thus obviously lends itself to some kind of regulation. We apply a fixed price/quantity regulation that, besides simplifying the model, prevents strategic interaction in the electricity

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10) All the equations of the perfect competition model are gathered in Kromann (2001). A thorough explanation of the supply system can be found in Hauch (2000).

market.[11] The prices and quantities chosen are those that would prevail under perfect competition.

To ensure the existence, uniqueness and optimality of an equilibrium in our model it is also necessary to deprive the fringe of the possibility of extraction-condensing production (see appendix B). This raises the problem of capacity composition with respect to technologies between the fringe and the oligopolists. We argue that fringe producers should be assigned only small scale technologies, as owners exercising market power are likely to own large scale plants and not bother with small scale technologies. In section 5 we discuss implications of alternative ways of distributing capacities between the fringe and oligopolies.

Were there no restriction on fringe technology choice, the simple solution would have been to assume that fringe and oligopolists had identical compositions of technologies. However, the requirement for no strategic interaction through district heating markets leaves us with no desirable alternative other than assigning all backpressure technologies to the fringe and supplementing these with condensing capacity until the desired fringe market share is reached.[12]

For pedagogical reasons, we first model a Cournot oligopoly, and thereafter we add a fringe. For the Cournot oligopoly we retain Hauch's modelling of the decentralized district heating condition.[13] For the reasons listed above this condition is altered when we introduce a competitive fringe.

We begin by presenting a more intuitive miniature version of the more complex models which simplifies the assumptions involved. Let us assume N

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11) With the possibility of strategic interaction a fringe supplier could be forced out of the market if the district heating price fell below the production costs. Such interaction does not seem very likely when the market is regulated.

12) The capacities assigned to the fringe in the two fringe scenarios are calculated so that the fringe under perfect competition supplies 40 and 20 per cent of the electricity market respectively.

13) We do not, however, use this model for simulations, as it violates our assumption that no strategic interaction can affect the district heating market. In this model, producers might shut down backpressure capacity in order to raise the electricity price. This would also have smaller district heating output and rising prices as side effects.

identical profit-maximizing Cournot oligopolists setting quantities with constant marginal costs and zero conjectural variations: $\max \Pi\left(q_j\right) = (P(\eta Q) - Qc)\eta q_j$, where $Q = (N-1)q_j + Q^{fri} + q_j$. q_j represents fuel input for oligopolist j, ηQ electricity output at industry level, c constant fuel costs, ηq_j electricity output for oligopolist j, and Q^{fri} fuel input for the fringe. The first order condition implies that

$$\eta c = MC = P(\eta Q) + P'(\eta Q)\frac{Q - Q^{fri}}{N} \tag{13}$$

The more oligopolies there are, the flatter the inverse demand curve is, and the larger fraction of output the fringe is responsible for, ceteris paribus, the closer the output price, $P(\eta Q)$, gets to marginal costs.[14]

4.1 Cournot Competition

Consider N large and identical producers of power. Each has an equal share (that is, $\frac{1}{N}$) of production, fuel use, capacity, and the imposed capacity requirements. The producers are price-takers on all markets but the markets for electricity. The problem is to maximize profits by choosing fuel and capital inputs knowing that the output choices will affect the price of electricity ($P_E(E)$ is a continuously decreasing and differentiable function). The supply of electricity by one oligopolist is then:

$$\sum_{k,i}\left(\frac{Cm_{k,i}}{1+Cm_{k,i}}\eta^b_{k,i}F^b_{k,i} + \eta^c_{k,i}F^c_{k,i}\right) = \frac{E}{N} \tag{14}$$

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14) To calculate analytically the slope of inverse demand $P'(\eta Q)$ is difficult, because our demand system is a deeply nested structure of utility and production functions. Instead we have simulated the slope of the demand curve with a Taylor approximation. We calculate the slope of the demand curve for a number of price and quantity pairs by adding a tiny fraction to the electricity price and then measuring the demand decrease. The parameters for our Taylor approximation are then found through an OLS regression on the generated data set. By solving the model and correcting as few as three consecutive times, the difference between the approximation of $P'(\eta Q)$ and the measured $P'(\eta Q)$ can be brought below $\frac{1}{1000}$.

As the producers are identical, the fuel efficiency relations, heat-electricity ratios, the two capacity constraints and the two district heating constraints are only slightly altered compared to the perfect competition situation. The price sensitivity of output is reflected, and the relations and constraints are simply multiplied by $\frac{1}{N}$ on both the right and left hand sides of the equations. These equations can be reviewed in Kromann (2001) together with the rest of the solution to the Cournot oligopolists' problem.

However, the production decisions for backpressure and condensing technologies are a little less straightforward. The corresponding first-order conditions from the Kuhn-Tucker solution are as stated in equations 15 and 16, but we note that the summarized expressions represent the electricity production of one Cournot oligopolist.

$$\begin{aligned} &\frac{Cm_{k,i}\,\eta^{b}_{k,i}}{1+Cm_{k,i}}P_E\left(E\right)+\frac{\partial E}{\partial F^{b}_{k,i}}P'_E\left(E\right)E \\ &-P^{F}_{k,i}-\lambda^{cap}_{k,i}+\frac{\eta^{b}_{k,i}}{1+Cm_{k,i}}\left(P^{H}_{i}-\left(d_k-\theta\right)\lambda^{dec}_{i}\right)\leq 0 \end{aligned} \qquad (15)$$

$$\eta^{c}_{k,i}P_E\left(E\right)+\frac{\partial E}{\partial F^{c}_{k,i}}P'_E\left(E\right)\sum_{k,i}E-P^{F}_{k,i}-\lambda^{cap}_{k,i}\leq 0 \qquad (16)$$

The identical oligopolists have the same first order conditions, and if all of these are satisfied then none of them have any incentive to alter their output decisions. The marginal change in total electricity supply due to one of the producers using slightly more fuel input in one technology is then still the fuel efficiency of this technology. Thus, the reaction function is characterized by:

$$\frac{\partial E}{\partial F^{b}_{k,i}}=\frac{\eta^{b}_{k,i}Cm_{k,i}}{1+Cm_{k,i}} \quad \text{and} \quad \frac{\partial E}{\partial F^{c}_{k,i}}=\eta^{c}_{k,i} \qquad (17)$$

Substituting this and equation 14 into equations 15 and 16 yields first order conditions. These are similar to those of the standard Cournot oligopolist quantity competition (here still with constant marginal costs); see equation 13, assuming $Q^F=0$.

4.2 Cournot Competition with Fringe Supply

As mentioned earlier in this section, a fixed quantity regulation is needed to avoid strategic interaction through the market for district heating. Both the fringe and the oligopolists are obliged to supply a negotiated amount of district heating. The fringe cannot supply centrally produced district heating, and thus does not need a decentralized district heating condition. The oligopolists produce both types of district heating and retain their decentralized district heating condition. Both types of producers get a condition of the type

$$\overline{H}_i - H_i \leq 0 \tag{18}$$

and cost minimization ensures that the condition binds with equality (as decentralized district heating is more costly). The constraint has the associated shadow value λ_i^{dih}. If the fringe is given backpressure or district heating capacity, the oligopolist's share of decentralized district heating, θ, must be adjusted accordingly. We will not present the fringe suppliers' problem here, as it is very similar to the problem of the producer under perfect competition. Instead, its solution is stated in appendix A.

The total supply of electricity is now

$$E = N \sum_{k,i} \left(\frac{Cm_{k,i} \eta_{k,i}^b}{1 + Cm_{k,i}} F_{k,i}^b + \eta_{k,i}^c F_{k,i}^c \right) + E_{k,i}^{fri}$$

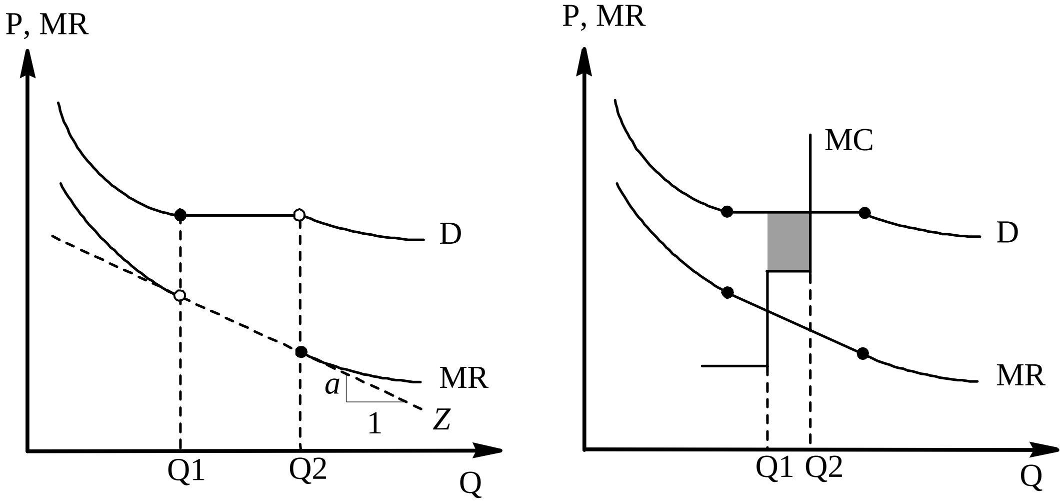
where E^{fri} denotes the total electricity production of the fringe suppliers. The introduction of fringe supply alters the Cournot model only slightly. The changes are to be found in the production decision conditions for electricity, which are shown below:

$$\left[\frac{\eta^{b}_{k,i}Cm_{k,i}}{1+Cm_{k,i}}P_{E}(E)+\frac{\partial E}{\partial F^{b}_{k,i}}P'_{E}(E)\frac{E-E^{fri}}{N}\right] + \frac{\eta^{b}_{k,i}}{1+Cm_{k,i}}\left(P^{H}_{i}+\lambda^{dih}_{i}+(d_{k}-\theta_{i})\lambda^{dec}_{k,i}\right)-P^{F}_{k,i}-\lambda^{cap}_{k,i}\leq 0 \qquad (19)$$

$$\left[\eta^{c}_{k,i}P_{E}(E)+P'_{E}(E)\frac{\partial E}{\partial F^{c}_{k,i}}\frac{E-E^{fri}}{N}\right]-P^{F}_{k,i}-\lambda^{cap}_{k,i}\leq 0 \qquad (20)$$

The stepwise cost structure of the fringe suppliers, which always supply at marginal cost, makes the demand curve perceived by the Cournot competitors kinked with horizontal sections as shown in figure 3a below.

Figure 3 Structure of the oligopolist's residual demand and costs



(a) (b)

When the price is lowered below the marginal cost of the fringe's marginal technology, its capacity is taken out of production, leaving more demand for the large suppliers.[15] At flat segments of the perceived demand curve

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[15] It seems natural that it is the fringe suppliers that exit the market, as the oligopolists earn profits while the fringe suppliers sell at marginal cost.

we choose to say that a fringe technology is forced out of the market. This corresponds to the following conditions:

$$
\begin{aligned}
\frac{\partial E}{\partial F^b_{k,i}} &= \begin{cases} \frac{\eta^b_{k,i} Cm_{k,i}}{1+Cm_{k,i}} & \text{when not forcing out the fringe} \\ 0 & \text{when forcing out the fringe} \end{cases} \\
\frac{\partial E}{\partial F^c_{k,i}} &= \begin{cases} \eta^c_{k,i} & \text{when not forcing out the fringe} \\ 0 & \text{when forcing out the fringe} \end{cases}
\end{aligned}
\qquad (21)
$$

The oligopolists' marginal revenue is equal to the market price P when they take over the demand supplied by the fringe technology that is forced out of the market. This is so because the total demand is unchanged (the fringe supply is substituted on a one-to-one basis by the oligopolistic supply). However, the oligopolists sell a larger quantity, and this affects their marginal revenue, because when the price decreases after a fringe technology is forced out, their profits are affected more because of the larger total quantity they sell.

From equations 19 and 20 it can be seen that the oligopolist's marginal revenue (square bracket terms) is also a function of his own production $\frac{E-E^{fri}}{N}$. As this increases while the fringe is forced out, the marginal revenue is lower at $Q2$ than $Q1$, because $P'(E) < 0$. In the figure the line Z has the slope a. It can be seen from the two equations that a is proportional to $P'(E)$, which is constant while the fringe is forced out because total demand is unchanged.

Until the inclusion of the fringe supply our different maximization problems have fulfilled the conditions that make them solvable by the Kuhn-Tucker necessary conditions: the profit function has continuous derivatives with respect to the input vector. This is not so with fringe supply included.

As we saw above, the marginal revenue is no longer continuous because it jumps to the price of electricity when a fringe technology is forced out. However, if we replace expression 21 with expression 17, our maximization problem would again qualify to be solved with the Kuhn-Tucker method, because this condition ensures that the MR curve becomes continous, as it will follow line Z in figure 3a between Q1 and Q2. These equations are similar to those of the standard Cournot oligopolist competition with fringe supply, cf. equation 13.

We could not, however, be sure that the solution found actually maximizes the oligopolists' profits. An example of this situation is shown in figure 3b. $Q1$ is the $MR = MC$ solution to this problem, but increasing supply to $Q2$ would not decrease the price, and thereby profits would increase by the amount represented by the shaded area.

Fortunately, the true profit maximizing input vector can still be found. In appendix B we show that only a small number of possible input vectors can maximize profits. One of these possibilities corresponds to the $MR = MC$ solution from the Kuhn-Tucker necessary conditions for the Cournot model with fringe mentioned above. The other possibilities correspond to cases (which in effect state that a specific output must be produced) with input decisions very similar to those of previously described models, except that the electricity price does not appear. Instead, an internal shadow price acts to choose the cheapest technologies for the production. The full model of Cournot competition with fringe supply can be found in appendix A.

5 Simulation Results

As our main simulations will relate prices under imperfect competition to perfect competition prices in 2005, it is useful to compare the actual prices under regulation to those of simulated perfect competition. To keep our study simple we compare the actual 1995 prices of electricity to simulated perfect competition prices. Liberalization has, however, not been introduced at the same time in the various Nordic countries. Norway was the first to liberalize early in the 1990s, followed by Sweden and Finland, whereas the Danish deregulation has taken place only recently.

It is not possible for the model to handle country-specific liberalization at different points in time. Instead, we report three counterfactual scenarios where liberalization takes place in 1995, 2000 or 2005 respectively. Table 1 shows indices for potential efficiency gain. The index is calculated as the difference between actual 1995 average electricity price and the simulated perfect competition price in the relevant year relative to the actual 1995 price.

The indices presented are found by depreciating capacities and updating national income according to the historical income growth figure, and then simulating perfect competition.

Table 1: Index for potential efficiency gain due to trade and reduced capital intensity

	Denmark	**Finland**	**Norway**	**Sweden**
1995	0.561	0.379	-0.016	0.523
2000	0.209	-0.118	-0.830	0.141
2005	0.012	-0.396	-1.285	-0.073

Note: The index is calculated as the difference between actual 1995 average electricity prices and the simulated perfect competition prices in the relevant year relative to the actual 1995 prices.

These scenarios must be interpreted very carefully, as the markets are not in long-run equilibrium. Generally a large index value means that the average payment is well above long-run marginal cost, while a small value indicates a very efficient power sector.

There are some negative values in the table. This does not indicate that producers become less efficient with liberalization. Rather, it indicates that the common Nordic market electricity price is higher than the actual 1995 prices which, unlike the common market price, are country specific. For example, the Norwegian consumers will pay more for electricity compared to actual 1995 prices, but will also earn substantially larger profits from their power producers. We present no welfare comparisons, however, as our partial equilibrium model does not offer adequate measures for this. As demonstrated by Farrel and Shapiro (1990) and others, horizontal mergers raising prices could be welfare improving.

In the table it can also be seen that early liberalizations tend to result in lower prices than later ones. This is caused by over-capacity, which postpones investments. Electricity price will then be equal to the short-run marginal costs, i.e. around the fuel input prices. However, as capacity depreciation causes supply to shrink, and demand rises because of larger income, investments take place when the price has risen enough to cover their capital costs.

One of the perils of the Danish regulation in particular was that capital intensity was not decided by the market interest rate. Rather, a non-profit principle applied, and this led to over-accumulation of capital. It is noteworthy that the Danish capacity in 1995 was so large that 10 years of depreciation and income growth was needed to bring the liberalized market price to the same level as the prices under regulation. Similarly, the Swedish power sector also seems to have had some overcapacity. The problem has not been so urgent in Finland.

Next, we turn to our main simulations. In table 2 we provide markups in 2005 measured by the Lerner Index (markup over wholesale price) for eight scenarios with different combinations of fringe size and number of Cournot oligopolists. In those scenarios which include fringe supply, the fringe has been given all the backpressure capacity. The fringe electricity production capacity has then been adjusted to either 40 or 20 percent of the market supply in a perfect competition simulation by adding condensing capacity.

Table 2 Lerner Index and Hirschman-Herfindahl Index (HHI)

	Lerner Index			**HHI**		
Fringe size	40%	20%	0%	40%	20%	0%
$N = 25$	14.4%	18.9%	20.5%	144	256	400
$N = 10$	30.2%	40.1%	43.2%	360	640	1000
$N = 3$	78.8%	94.5%	●	1200	2133	3333

Note: The Lerner Index is measured as the difference between price under imperfect competition and the price under perfect competition relative to the price under imperfect competition. The size of the fringe capacity is adjusted so that the fringe has a 40 or 20 per cent market share under perfect competition.

For each of the combinations of number of competitors and fringe share size, the table also has a calculation of the Hirschman-Herfindahl Index (HHI), which is widely used to give easy overview of the concentration in an industry.[16]

The U.S. Federal Trade Commission and the Department of Justice (1992) "divides the spectrum of market concentration as measured by the HHI into three regions that can be broadly characterized as unconcentrated (HHI below 1000), moderately concentrated (HHI between 1000 and 1800), and highly concentrated (HHI above 1800)." In an "unconcentrated market" the markup in our simulations apparently makes up 43 per cent of the price. This finding

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16) The index is calculated as the sum of squares of all market shares measured in per cent.

replicates the results of Borenstein et al. (1999), who investigate the Californian electricity market.

It can be seen from table 3 that the impact on Nord Pool prices compared to perfect competition prices is less than should be expected, especially in some of the scenarios with high concentration. This is because demand is depressed when prices are high, and consequently electricity is produced with low cost technologies. In scenarios with a Lerner Index in the range of 80-95 per cent, the marginal technology is hydro power.

Table 3 Percentage price increase at the Nord Pool wholesale market compared to perfect competition

Fringe size	40%	20%	0%
$N = 25$	16.7	23.2	25.9
$N = 10$	43.5	66.7	75.9
$N = 3$	126.9	240.7	●

The relative increase in market prices (taxes included) for business and households in the Nordic countries compared to a perfect competition outcome (not shown) is not as drastic as the wholesale price hikes in table 3 would suggest. This is because electricity is excise taxed and costs of distribution are added.

As a sensitivity test, another setup has the electricity-other energy nest elasticities (see figure 1) tripled. It can be seen from table 4 that this has only a modest effect.

Table 4 Sensitivty analysis: Lerner index with trippled elasticities

Fringe size	40%	20%	0%
$N = 25$	10.2%	13.6%	14.8%
$N = 10$	20.4%	30.1%	33.5%
$N = 3$	62.9%	87.8%	●

We noted in section 4 that it is problematic to distribute the capacity between the fringe and the oligopolists without leaving room for strategic interaction through the district heating market. We have presented a model where the markets for centralized and decentralized production of district heating are separated and where the fringe possesses all the backpressure technologies. However, we have also simulated a scenario (not shown) where the fringe has no district heating production at all. The markups found here differ from those in table 2 by no more than two percentage point. Other scenarios where we have assumed away the strategic interaction show similar results.[17]

6 Conclusion

Our findings suggest that large producers in the Nordic market for electricity might be able to gain considerable market power and that this could be used to raise the electricity price substantially above marginal cost, even though the concentration in the market by a traditional measure, the Hirschman-Herfindahl Index (HHI), is only low or modest. This is in accordance with other research. However, some qualifications apply to our findings.

The British experience is that actual market price mark-up above marginal cost is smaller than predicted by theoretical models. The incumbent producers may be dampening prices in order either to deter new entrants or to prevent regulatory action. Such price restraining motives are not reflected in the present analysis.

On the other hand, the preferred market structure, Cournot competition, implies that producers behave in a non-cooperative manner. Cooperative behaviour can facilitate above-cost prices which are higher than reported in the present analysis.

An important policy implication of the analysis is that competition authorities in the Nordic countries should collaborate on monitoring the Nordic electricity market. In this connection it is important to develop indicators answering the following crucial question: is spare capacity in a situation with high electricity prices real, i.e. caused by inavoidable maintenance, or does it reflect abuse of market power?

17) The scenarios are available upon request.

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A Cournot Oligopoly with Fringe

Below is shown the full supply system for Cournot oligopoly with fringe. Some equations run over (k, i) or i:

$$E = E^{cou} + E^{fri} \tag{1}$$

$$E^{cou} = \sum_{k,i} E^b_{k,i} + E^c_{k,i} \tag{2}$$

$$H = \sum_{k,i} H^b_{k,i} + H^p_{k,i} + H^{fri}_{k,i} \tag{3}$$

$$E^b_{k,i} = \frac{Cm_{k,i}}{1 + Cm_{k,i}} \eta^b_{k,i} F^b_{k,i} \tag{4}$$

$$E^c_{k,i} = \eta^c_{k,i} F^c_{k,i} \tag{5}$$

$$H^p_{k,i} = \eta^p_{k,i} F^p_{k,i} \tag{6}$$

$$Cm_{k,i} = \frac{E^b_{k,i}}{H^b_{k,i}} \tag{7}$$

$$F^b_{k,i} + F^c_{k,i} + F^p_{k,i} - K^{ini}_{k,i} - K^{inv}_{k,i} \le 0 \tag{8}$$

$$\sum_{k,i} [\theta_i - d_k] \left(\frac{\eta^b_{k,i} F^b_{k,i}}{1 + Cm_{k,i}} + \eta^b_{k,i} F^p_{k,i} \right) \le 0 \tag{9}$$

$$K^{ini}_{k,i} + K^{inv}_{k,i} - K^{max}_{k,i} \le 0 \tag{10}$$

$$-\overline{H_i} + \sum_k \left(\frac{Cm_{k,i}}{Cm_{k,i} + 1} \eta^b_{k,i} F^b_{k,i} + \eta^p_{k,i} F^p_{k,i} \right) \le 0 \tag{11}$$

$$\begin{aligned} &\frac{\eta^b_{k,i} Cm_{k,i}}{1 + Cm_{k,i}} P_E(E) + \frac{\eta^b_{k,i} Cm_{k,i}}{1 + Cm_{k,i}} P'_E(E) E \\ &+ \frac{\eta^b_{k,i}}{1 + Cm_{k,i}} P^H_i - P^F_{k,i} - \lambda^{cap}_{k,i} - \frac{\eta^b_{k,i}}{1 + Cm_{k,i}} \left((d_k - \theta_i) \lambda^{dec}_{k,i} - \lambda^{dih}_i \right) \le 0 \end{aligned} \tag{12}$$

$$\eta^c_{k,i} P_E(E) + \eta^c_{k,i} P'_E(E) E - P^F_{k,i} - \lambda^{cap}_{k,i} \le 0 \tag{13}$$

$$\eta^p_{k,i} \left(P^H_i - \lambda^{dih}_i \right) - P^F_{k,i} - \lambda^{cap}_{k,i} + \eta^p_{k,i} (d_k - \theta_i) \lambda^{dec}_i \le 0 \tag{14}$$

$$\lambda^{cap}_{k,i} - \lambda^{max}_{k,i} - P^K_{k,i} \le 0 \tag{15}$$

$$\lambda_{k,i}^{cap} = 0 \quad \vee \quad \text{Equation 8 with strict equality} \tag{16}$$

$$\lambda_{i}^{dec} = 0 \quad \vee \quad \text{Equation 9 with strict equality} \tag{17}$$

$$\lambda_{k,i}^{max} = 0 \quad \vee \quad \text{Equation 10 with strict equality} \tag{18}$$

$$\lambda_{i}^{dih} = 0 \quad \vee \quad \text{Equation 11 with strict equality} \tag{19}$$

$$F_{k,i}^{b} = 0 \quad \vee \quad \text{Equation 12 with strict equality} \tag{20}$$

$$F_{k,i}^{c} = 0 \quad \vee \quad \text{Equation 13 with strict equality} \tag{21}$$

$$F_{k,i}^{p} = 0 \quad \vee \quad \text{Equation 14 with strict equality} \tag{22}$$

$$K_{k,i}^{inv} = 0 \quad \vee \quad \text{Equation 15 with strict equality} \tag{23}$$

$$E^{fri} = \sum_{k,i} E_{k,i}^{b,fri} + E_{k,i}^{c,fri} \tag{24}$$

$$E_{k,i}^{b,fri} = \frac{Cm_{k,i}}{1 + Cm_{k,i}} \eta_{k,i}^{b} F_{k,i}^{b,fri} \tag{25}$$

$$E_{k,i}^{c,fri} = \eta_{k,i}^{c} F_{k,i}^{c,fri} \tag{26}$$

$$Cm_{k,i} = \frac{E_{k,i}^{b,fri}}{H_{k,i}^{b,fri}} \tag{27}$$

$$F_{k,i}^{b,fri} + F_{k,i}^{c,fri} - K_{k,i}^{fri} \leq 0 \tag{28}$$

$$\sum_{k,i} H_{k,i}^{b,fri} = \overline{H}_{i}^{fri} \tag{29}$$

$$\eta_{k,i}^{c,fri} - P_{k,i}^{F} - \lambda_{k,i}^{fri} \leq 0 \tag{30}$$

$$\frac{\eta_{k,i}^{b}}{1 + Cm_{k,i}} \left(P_{i}^{H} + Cm_{k,i} P_{E} \right) - P_{k,i}^{F} - \lambda_{k,i}^{fri} - \lambda_{i}^{fdih} \leq 0 \tag{31}$$

$$\lambda_{k,i}^{fri} = 0 \quad \vee \quad \text{Equation 28 with strict equality} \tag{32}$$

$$\lambda_{i}^{fdih} = 0 \quad \vee \quad \text{Equation 29 with strict equality} \tag{33}$$

$$F_{k,i}^{b,fri} = 0 \quad \vee \quad \text{Equation 31 with strict equality} \tag{34}$$

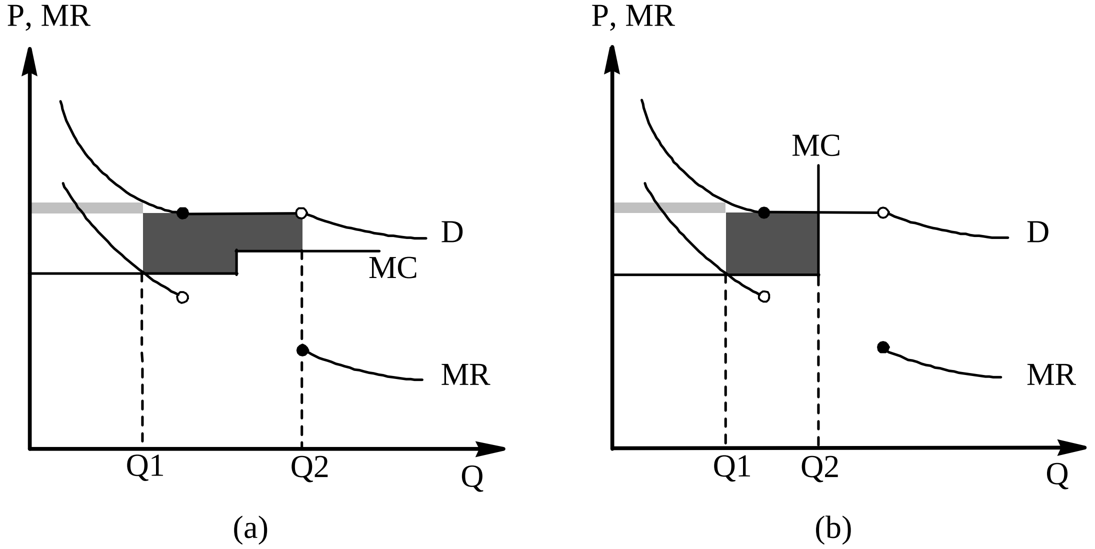
$$F_{k,i}^{c,fri} = 0 \quad \vee \quad \text{Equation 30 with strict equality} \tag{35}$$

B Proof of Existence, Uniqueness and Optimality of Equilibrium of Cournot Oligopoly with Fringe

By lowering prices by a fraction, the large suppliers might be able to force out the marginal technology of the fringe. As the large suppliers' output is priced above their marginal cost, such a strategy might be profitable if the fringe technology forced out has a large capacity and a marginal cost only a little lower than the ordinary Cournot equilibrium price reached by the large suppliers. Such a situation is illustrated in figure 4a, where the light shaded area is the profit gain associated with the $MR = MC$ solution, and the dark shaded area is the profit gain associated with forcing out the fringe.

It might also happen (figure 4b) that the large suppliers do not have the efficient capacity (with marginal costs lower than market price) sufficient to meet the demand if all the capacity of the marginal fringe technology is forced out of the market. In this case the large suppliers would prefer to let the fringe produce with some part of their marginal technology, rather than supplying the excess demand with marginal losses (their remaining capacity has costs higher than the market price).

Figure 4 Ambiguous cost structure



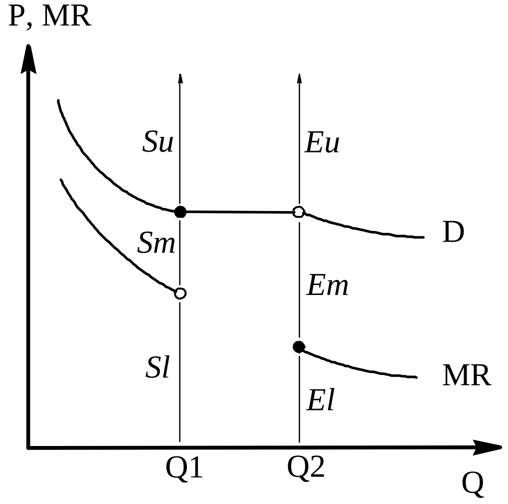
Apparently there are situations where the $MR = MC$ equilibrium found by our solution to the Cournot competitors' problem may not maximize profits.

This happens only when the fringe can be wholly or partly forced out of the market. Fortunately we can show that these situations, which we call ambiguity between perceived demand and cost structure, restrict themselves to one of these two sufficient conditions:

- when the price is equal to the cost of the fringe's marginal technology, but where the fringe production in this technology is zero.
- when the large suppliers produce at the capacity limit of some technology.

To show that this claim is correct we need to consider the large suppliers' marginal cost when they start to force out a marginal fringe technology and when they have just forced it out. Figure 5 gives a useful classification of all possible cost structures related to a given fringe technology that may or may not be forced out to increase profits.

Figure 5 All possible cost structures



Our classification has six distinct types, as the three remaining logical combinations of intersections are not feasible because MC is nondecreasing:

1. An MC curve that intersects *Su* and *Eu*. Figure 6a shows that MC is above the price for the whole of the horizontal section, so forcing out

the fringe technology will always decrease the profit. Also, it cannot be profitable to force out any fringe technologies to the right of $Q1$. However, there might be a fringe technology with higher marginal cost (another flat piece on the perceived demand curve which is not shown in the figure) that could be forced out of the market. The cost structure associated with this could be any of types 1 to 6.

2. An MC curve that intersects *Sm* and Em. Figure 4a presented above shows this situation. The light shaded area is the profit associated with the $MR = MC$ solution (quantity $Q1$), while the dark shaded area is the profit associated with just forcing the fringe's technology out of the market (quantity $Q2$). Whether it is profitable to leave the former solution in favour of the latter depends on the precise structure of cost and demand.

3. An MC curve that intersects *Sm* and Eu. Figure 4b presented above shows this situation. The light shaded area is the profit associated with the $MR = MC$ solution (quantity $Q1$), while the dark shaded area is the profit associated with using all of the capacity with marginal costs lower than those of the fringe's marginal technology (quantity $Q2$). Whether it is profitable to leave the former solution in favour of the latter depends on the precise structure of cost and demand.

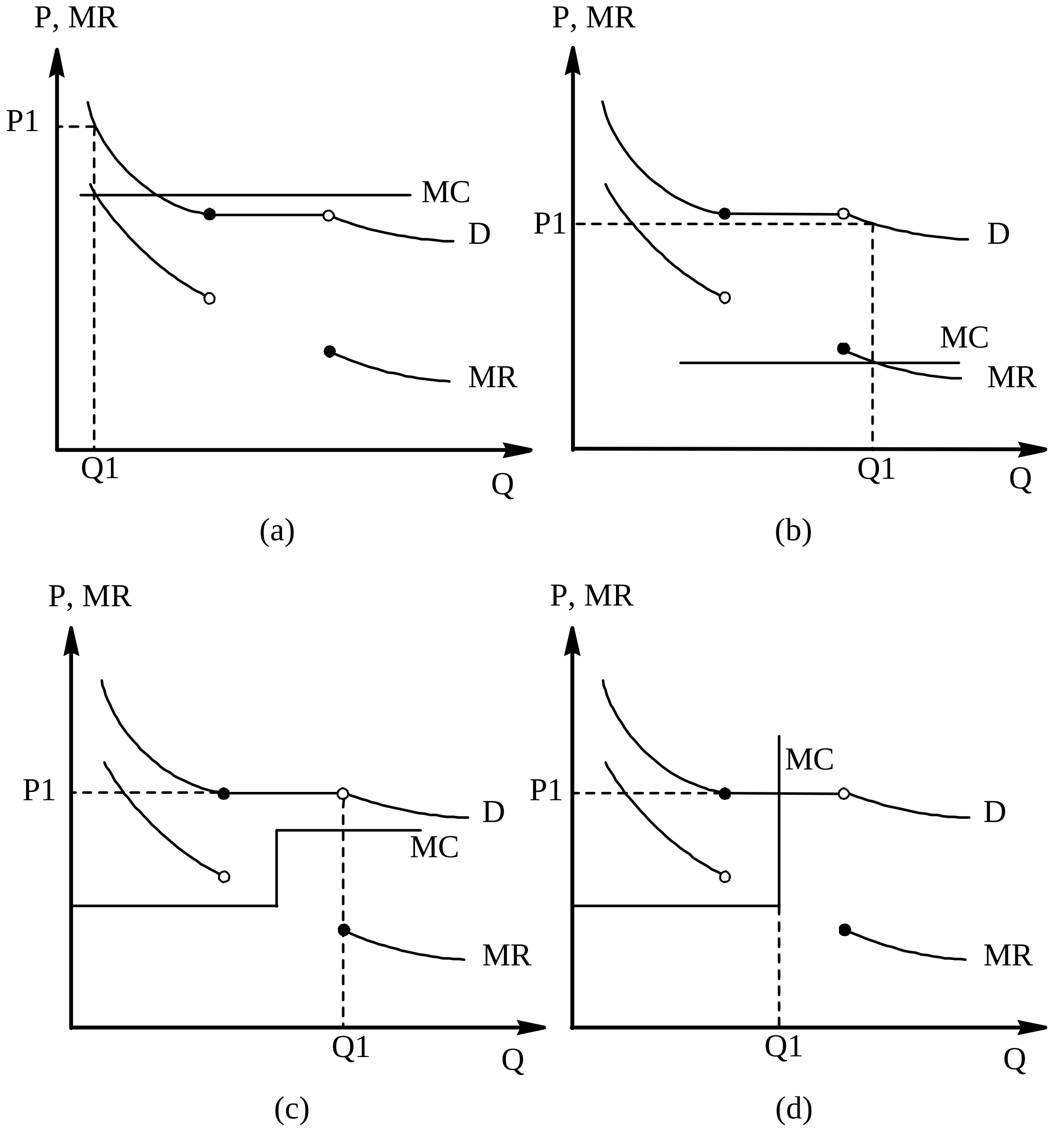
4. An MC curve that intersects *Sl* and El. As can be seen in figure 6b, $MR > MC$ for all quantities left of $Q1$. Thus it is always profitable to move rightward towards this point. It may be profitable to move even further rightward if there is an even cheaper fringe technology that may be forced out. The cost structure relating to this particular fringe technology would then be of type 1, 2 or 3.

5. An MC curve that intersects *Sl* and Em. Figure 6c depicts this situation, and it is obvious that it will always be more profitable to choose the quantity $Q1$ than any other quantity.

6. An MC curve that intersects *Sl* and Eu. Again, in figure 6d $Q1$ is more profitable than any other quantity.

From this we see that ambiguity is associated with just forcing the fringe technology out of market (type 2) and capacity limits of large suppliers' technologies (type 3). In the remaining four possible cost structures there can be no ambiguity, and this confirms our claim.

Figure 6 Unambiguous cost structures



Note that this proof assumes that the oligopolists' and the fringes' cost structures do not change while a fringe technology is being forced out. This is the reason that the fringe and the oligopolists are assumed to supply separate district heating markets. If they supplied the same markets, forcing out a fringe backpressure technology might change the cost minimization problem of the oligopolist (because a larger district heating quantity requirement has to be met), thus altering the resulting marginal cost curve.

For the same reason, the fringe cannot possess extraction technologies. Forcing out some fringe backpressure technology would then be likely to change the heat/electricity ratio of some of the fringe's extraction technologies. This would alter the amount of electricity supplied inframarginally by the fringe, and the oligopolists' perceived demand curve would thereby be shifted inwards or outwards, depending on whether the fringe produced more or less electricity. By only allowing the fringe condensing and backpressure technologies there is no inframarginal change in the fringe supply. Only the production in marginal fringe technology is changed, as the inframarginal technologies are used to their capacity limit.